(1)

NDE OF BLACK HAWK HELICOPTER ROTARY WING-HEAD SPINDLE THREADS USING ELECTRIC CURRENT PERTURBATION

By

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Six Black Hawk helicopter rotary wing-head spindles were inspected for flaws in the thread roots using the electric current perturbation (ECP) method. Both new spindles and spindles which had been removed from service were examined. The ECP method was shown to provide much higher sensitivity for detection of surface and slightly subsurface flaws than the presently-used ultrasonic method. In addition, ECP is not influenced by the presence of a tie rod in the spindle bore. A laboratory demonstration of the flaw detection capability of ECP was held for representatives of USAAVSCOM and Sikorsky Aircraft.

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I. INTRODUCTION AND SUMMARY

A recent crash of a Black Hawk helicopter was caused by a rotary wing-head spindle failure resulting from a fatigue crack initiating in a thread root. Crashes of two S76 helicopters, which use a similar spindle design, have resulted from the same cause.

Because of the Black Hawk spindle failure, an ultrasonic inspection is now being performed on the spindle to detect fatigue cracks in the thread roots. The ultrasonic method has several disadvantages, however. These include low sensitivity to small cracks (the calibration flaw size is 0.25 in. long x 0.020 in. deep), low sensitivity to tightly closed cracks, and inability to perform an inspection after the installation of a tensioned tie rod. A tie rod is being installed in each spindle in the fleet to reduce the load carried by the threaded region.

An investigation initiated by the Army in 1981 (Contract No. DLA900-79-C-1266) showed that the ECP nondestructive evaluation method has a high degree of sensitivity for detection of fatigue cracks in the thread roots of the Black Hawk helicopter spindle.(1) The objective of the present project was to re-establish the ECP laboratory inspection system developed under the previous contract and to inspect several spindles which had been removed from service. If these spindles contained fatigue cracks, then ECP inspection data could be obtained from actual service-induced cracks.

During the course of the project, additional fixturing was built to accommodate the new spindle design (-103) which has a larger diameter than the older design(-102). A new ECP probe was built which could be positioned in the thread root instead of on the thread crest; however, testing of this probe was halted due to lack of time and uncertainty of improved results. Target flaws (EDM slots) were machined in a "standard" specimen consisting of a threaded section cut from a -103 design spindle. A meeting between Army, Sikorsky Aircraft, and SwRI personnel was held at SwRI to discuss plans for spindle inspections. Also, a two-day demonstration of the ECP method was conducted for USAAVSCOM and Sikorsky personnel.

ECP data were obtained from a -102 design "standard" spindle (used in the previous project) which contained EDM slots, the -103 "standard" specimen which contained EDM slots, a spindle removed from service which yielded an ultrasonic indication, a spindle with 12.6 service hours, and two new spindles.

The source of the ultrasonic indication obtained from one spindle was apparently not caused by a fatigue crack in a thread root since the indication was from below the surface. An ECP indication was not obtained from this region of the spindle. If the source of the ultrasonic indication is a subsurface anomaly, the ECP method would not be highly sensitive to a flaw of this type since the ECP probe is presently configured for surface and slightly subsurface flaws. Small ECP indications were obtained in the first thread of the 12.6 hour spindle and the last few threads of a new spindle. The source of these indications has not been identified as this was beyond the scope of the project.

The 12.6 hour spindle and one new spindle had tie rods installed, while no rods were present in the other spindles. The ECP signals were not influenced by the presence of the rods. Overall results indicate that the ECP method is very promising for spindle thread inspection.

II. EXPERIMENTAL ARRANGEMENT

A. Specimens

The specimen set consisted of two "standard" specimens containing EDM slots for obtaining an ECP response from known flaws and four spindles for which SwRI was given very limited information as to the presence of flaws. In one spindle an ultrasonic indication had previously been obtained by the manufacturer. This indication was from an unknown source, apparently well below the thread root surface. Specimen details are given in Table I. EDM flaw sizes and locations (thread number) in the two "standard" specimens are given in Table II. In this report, the threads are numbered beginning at the splines, i.e., the first thread from the splines is thread No. 1.

B. Laboratory Setup

A laboratory setup was established which allowed the spindles to be simultaneously rotated and translated axially by means of a motor drive and lead screw arrangement. The ECP probe remained stationary and the relative motion between the probe and spindle provided a helical scan so that the probe maintained a fixed relationship with respect to the threads. This arrangement minimized influence of the thread geometry on the overall signal response. The probe rode on an air bearing to eliminate contact with the thread surface. Two air bearing blocks were matched to the respective -102 and -103 spindle threads. The probe scan direction with respect to the spindle is shown in Figure 1. The "missing spline" as shown in the figure is typically used as a reference position. Rotational speed was 5.26 rpm.

An ECP probe which utilizes a noncontacting induction method for establishing current flow and for sensing current perturbations associated with defects was configured to ride on the crest of the threads. This probe provides current flow perpendicular to the thread at a frequency of 100 KHz which provides optimum detection of small fatigue cracks which grow along the thread root. A second probe which rode in the thread root was built to determine if the flaw detection sensitivity could be improved; however, testing of this probe was halted due to lack of time and uncertainty of improved results.

Analog ECP signals were digitized as a function of probe position using a Nicolet model 2090-III digital oscilloscope and were transferred to a Tektronix 4052 computer for signal processing and plotting. To provide enhancement of the flaw signals, a digital high-pass filter routine was used to reject the lower frequency signal components not associated with defects. The digital filter was used for convenience in this investigation; an analog filter could be used in inspection hardware.

TABLE I

SPINDLES INSPECTED USING ECP

Specimen No.	Spindle Type	Serial No.	Tensioned Rod	Remarks
1	-102	A204-00086	No	- Contains EDM slots - used in previous previous program
2	-103	None	No	- Referred to as Short Standard #22. - Contains EDM slots - Severe Thread Deformation in some areas
3	-103	A204-00786	No	- Referred to as "Ft. Campbell Spindle" - Removed from service; service hours unknown - Ultrasonic subsurface indication
4	-103	A204-02264	Yes	- 12.6 service hours
5	-103	A204-02336	No	- 0 service hours
6	-103	A204-02280	Yes	- 0 service hours

TABLE II

EDM FLAW SIZES IN SPECIMENS #1 AND #2

Specimen No.	Flaw Designation	Flaw Length (in.)	Flaw Depth (in.)	Location (Thread No.)	Shape
1	E*	0.052	0.014	10	Thumbnail
	F	0.039	0.010	10	Thumbnail
	G	0.021	0.009	10	Thumbnail
2	J	0.040	0.004**	2	Rectangular
	K	0.040	0.015	5	Rectangular
	L	0.020	0.003	9	Rectangular
	M	0.040	0.006	15	Rectangular

* The flaw designations in Specimen 1 correspond to those used in the previous project[1]. Letters A-D and H-I were also used previously and are not used here.

**This is an approximate depth since the flaw is located on the slope of the thread and the true depth is difficult to determine.

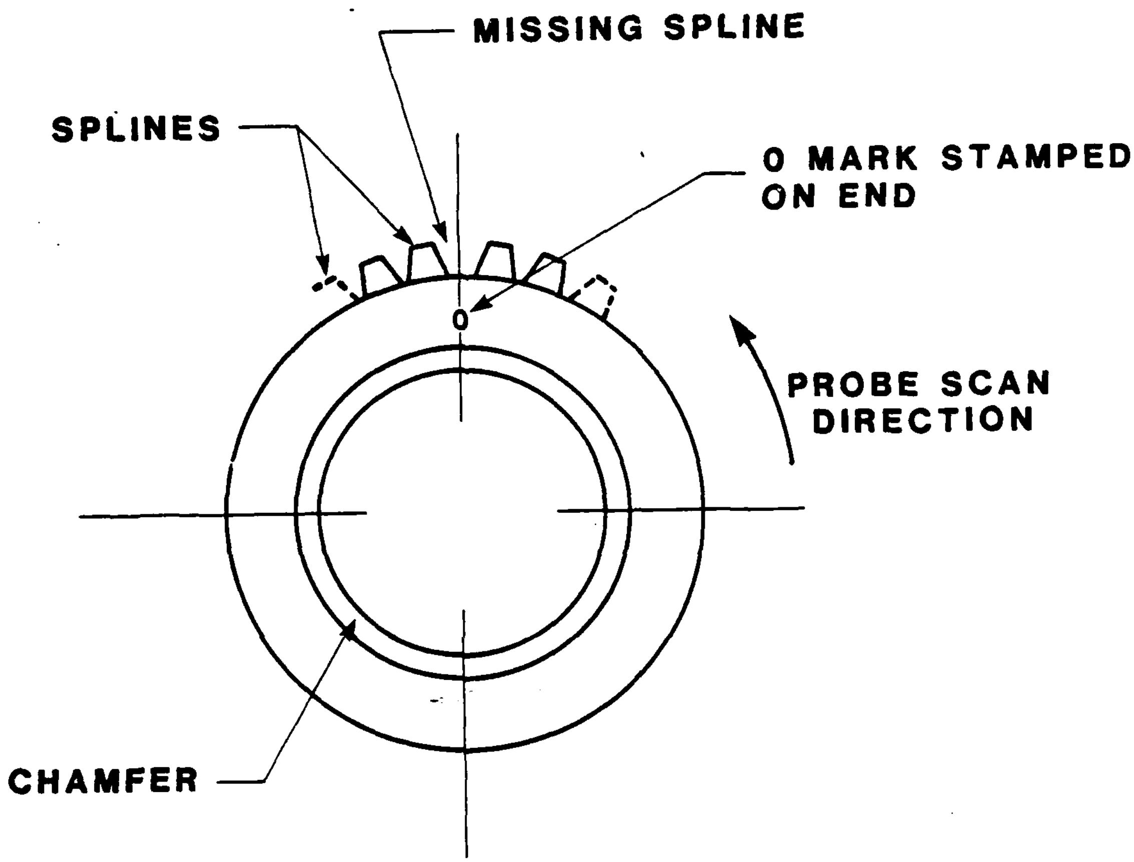

FIGURE 1. ECP PROBE SCAN DIRECTION LOOKING INTO THREADED END OF SPINDLE

III. EXPERIMENTAL RESULTS

Specimen No. 1

ECP data were initially obtained from "standard" specimen No. 1 (used in the previous project) to establish the laboratory setup. This spindle was of the older design (-102). Only the threads in the area of the flaws were scanned. ECP signals from artificial flaws E, F, and G in specimen No. 1 are shown in Figure 2. Distinct signals are obtained from all three flaws including the smallest (flaw G) which is 0.021 in. long x 0.009 in. deep. Note that satellite signals (E' and F') are obtained from the larger flaws (E and F) when the probe is located over adjacent threads. Flaw F (0.039 in. L. x 0.010 in. D.) gives a signal-to-background ratio greater than 2:1 when compared to the background signals from spindles 1 through 6.

Specimen No. 2

ECP data were obtained from an artificial flaws in specimen No. 2 so that signals could be obtained from known flaws in a -103 design spindle. ECP signals from a scan of all the threads in specimen No. 2 are shown in Figures 3 through 6. Due to the long scan path, the data are shown on four separate figures, each representing four threads. Note that one region of the threads in this specimen had previously been severely deformed to prevent the spindle from being re-used. The deformation resulted in large extraneous ECP signals which would not normally be present.

A flaw-like ECP indication was obtained in the first thread at a position corresponding to the missing spline (Figure 3). The source of this indication is not clear; however, it is unlikely that it is caused by a flaw since an indication was obtained at the same location on each of the spindles inspected. It is possible that the ECP probe is actually sensing the missing spline.

A signal from flaw J (0.040 in. L. x 0.004 in. D.) is also shown in Figure 3. Note that the signal amplitude from this flaw is slightly greater than the background signal level in regions where no flaws and no thread deformation are present. ECP signals from flaw K (0.040 in. L. x 0.015 in. D.) are shown in Figure 4. Note that a satellite signal, K', is obtained when the probe is positioned over an adjacent thread.

Flaw L (0.020 in. L. x 0.003 in. D.) was not detected (Figure 5). This is not surprising since this flaw is very shallow. Flaw M which is located in thread 15 near the end of the spindle is in a region where the background noise level is high due to mechanical vibration caused by the probe holder extending beyond the end of the spindle (Figure 6). Therefore, a signal from this flaw is not apparent. This problem could be corrected by re-design of the probe bearing block if it is necessary to scan all of the threads. Because of this problem, the last thread was not scanned in all of the spindles.

Specimen No. 3

Specimen No. 3 was referred to as the "Ft. Campbell Spindle" and an ultrasonic indication from an unknown source had previously been obtained (by Sikorsky Aircraft) in this spindle. SwRI was provided very limited information

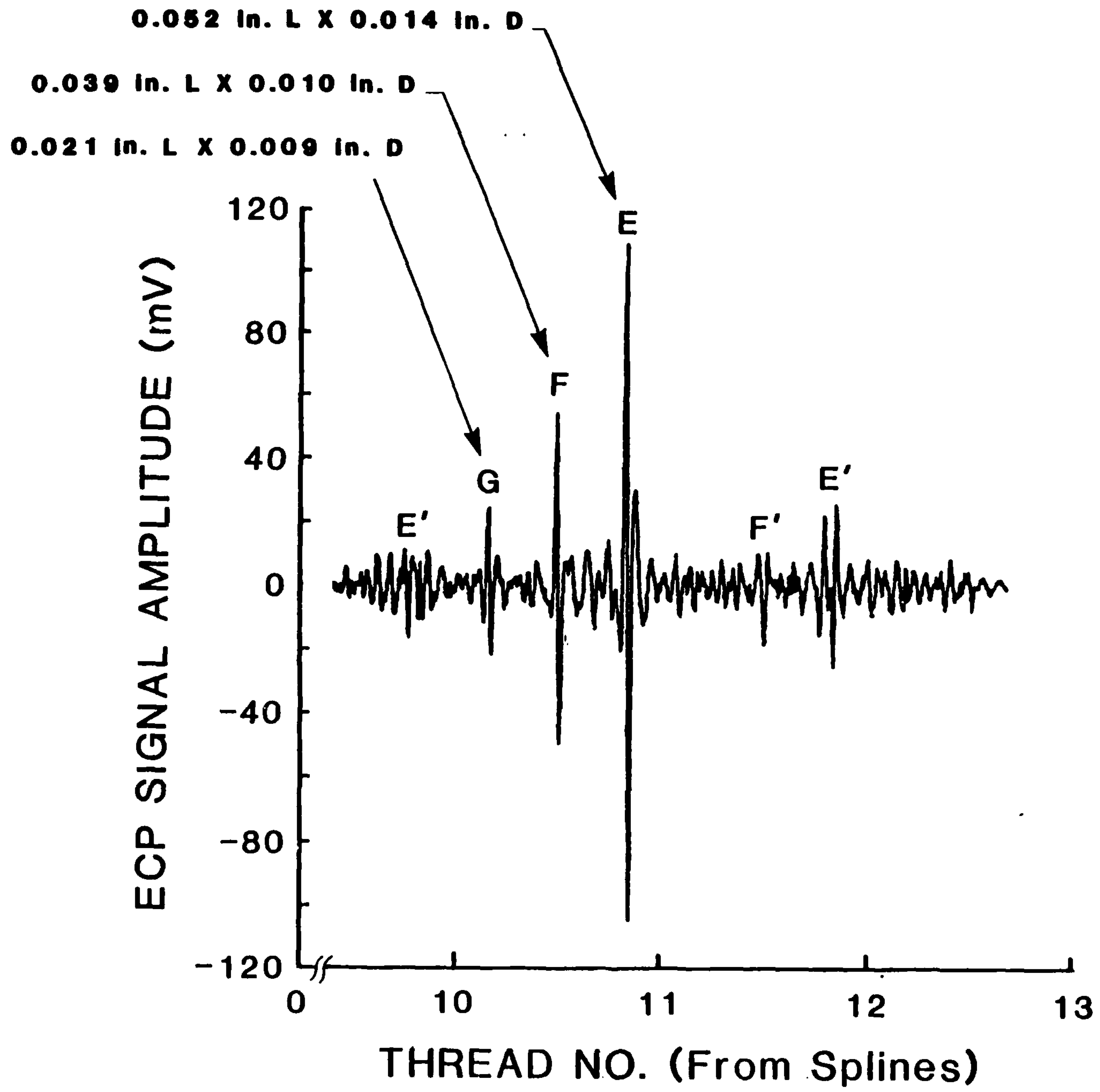

FIGURE 2. ECP SIGNALS FROM FLAWS E, F, AND G IN SPECIMEN NO. 1. SIGNALS OBTAINED WHEN THE PROBE IS LOCATED OVER THE ADJACENT THREAD ARE DESIGNATED E', AND F'. FLAW DIMENSIONS ARE LENGTH X DEPTH.

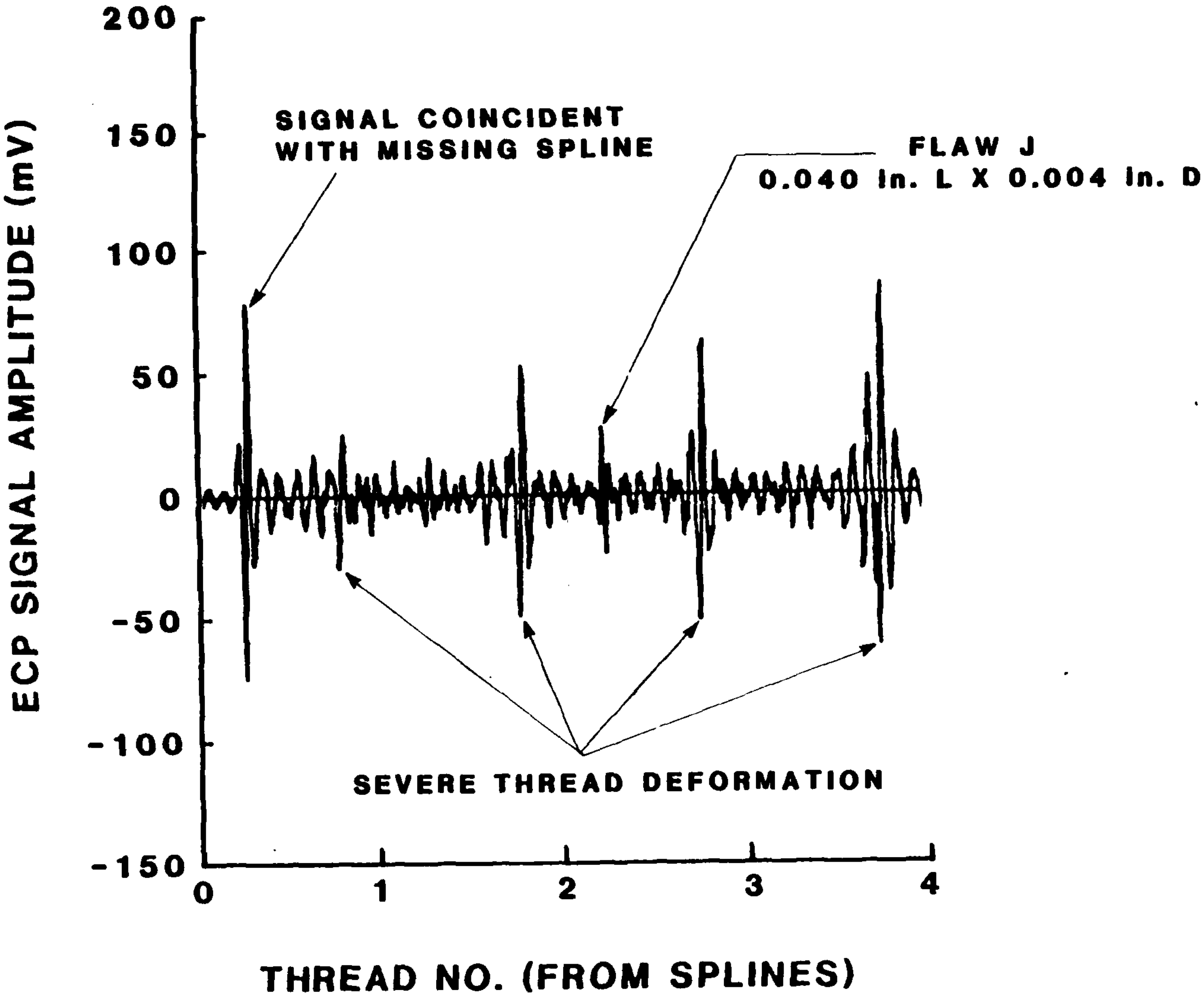

FIGURE 3. ECP SIGNALS FROM SPECIMEN NO. 2, THREADS 0-4

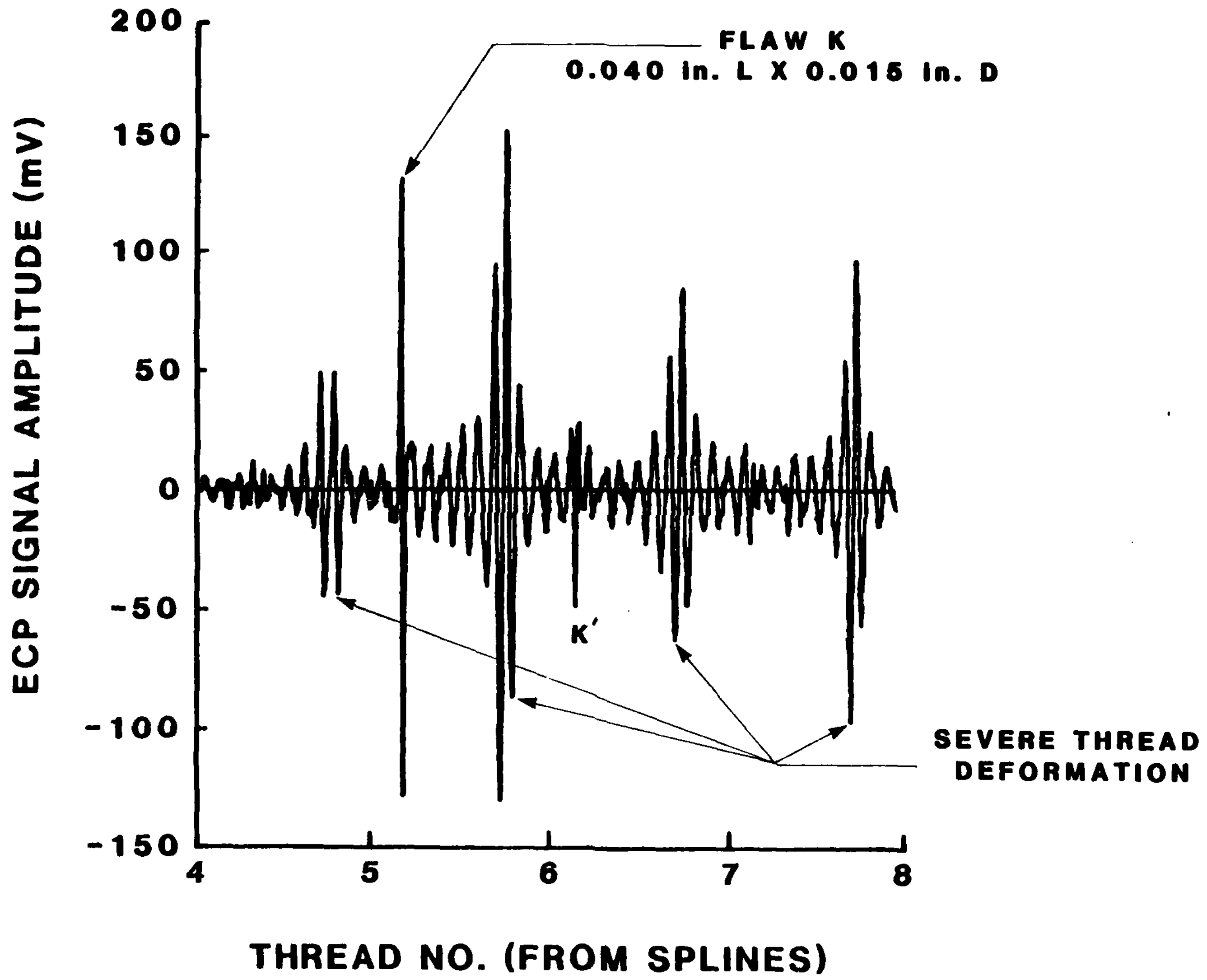

FIGURE 4. ECP SIGNALS FROM SPECIMEN NO. 2, THREADS 4-8

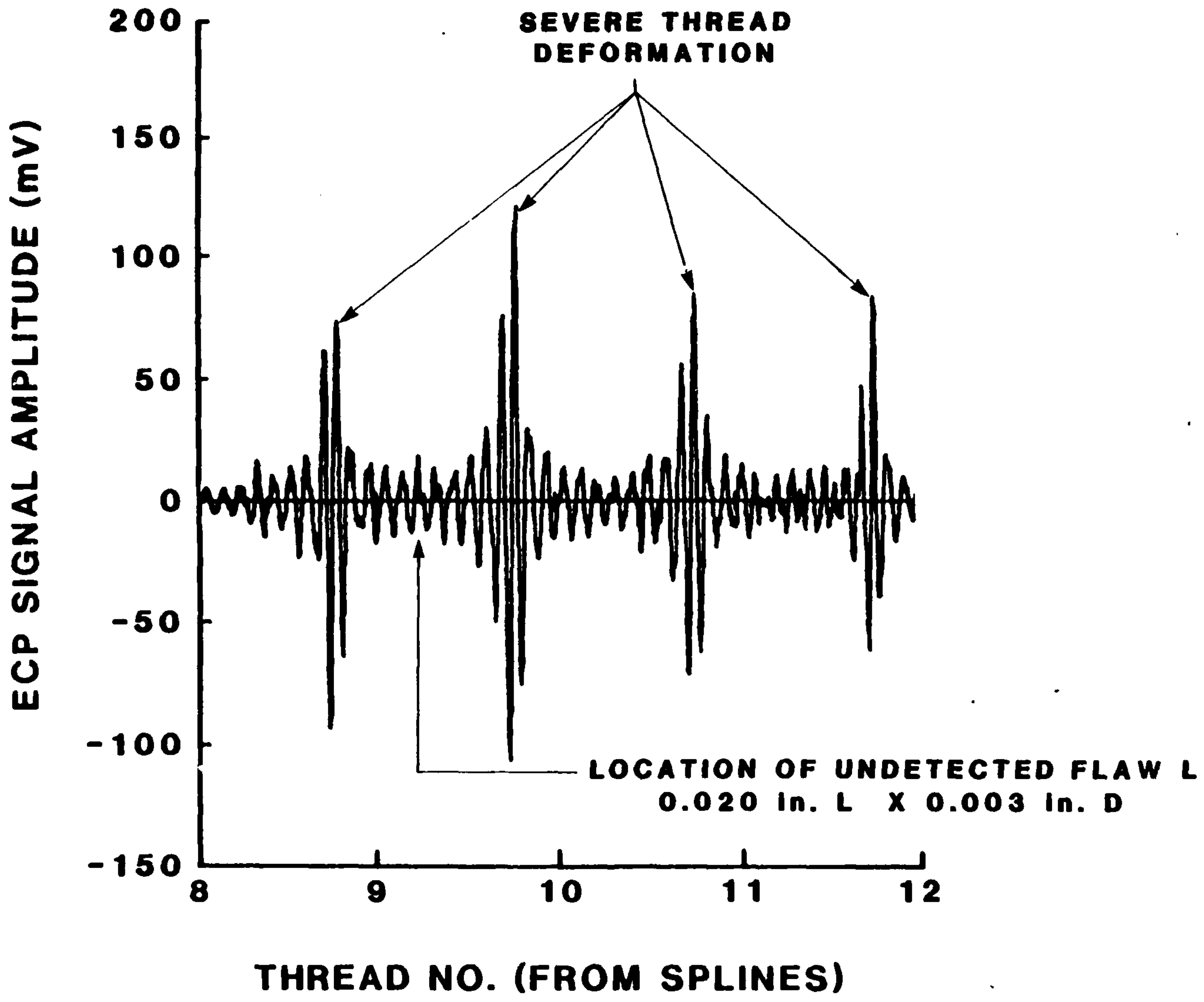

FIGURE 5. ECP SIGNALS FROM SPECIMEN NO. 2, THREADS 8-12

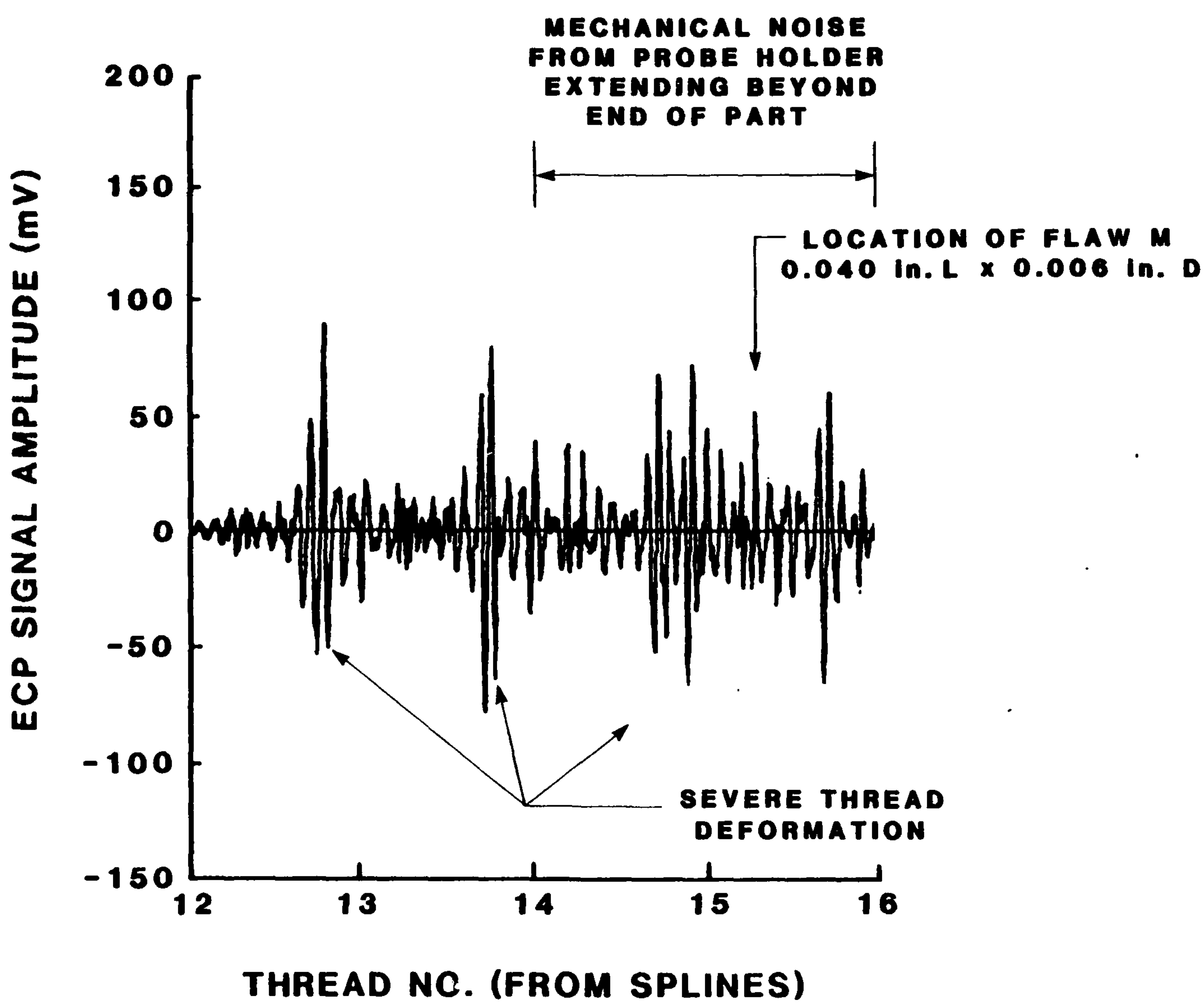

FIGURE 6. ECP SIGNALS FROM SPECIMEN NO. 2, THREADS 12-16

as to the location and other details of the indications; however, the indication was apparently from well below the thread root surface which would indicate that it most likely was not caused by a fatigue crack. No ECP indications were obtained from this spindle except for the signal coincident with the missing spline which was observed on the other spindles as well. The ECP data from spindle No. 3 are shown in Figures 7 through 10. Note that the vertical scale has been expanded compared to Figures 3 through 6. The signal coincident with the missing spline is evident in Figure 7. The background signal level from the remainder of the spindle is relatively uniform and no distinct flaw indications are evident.

Provided an actual subsurface flaw exists as indicated by the ultrasonic inspection, the ECP probe used here would not necessarily be sensitive to it since the probe is designed for detection of surface and slightly subsurface flaws. A metallurgical analysis to determine the source of the ultrasonic flaw indication is apparently planned by Sikorsky Aircraft.

Specimen No. 4

The ECP data from spindle No. 4 which has 12.6 service hours are shown in Figures 11 through 14. This spindle contained a tie rod and no effect of the rod on the ECP signal could be determined. A small indication, slightly above background signal level, was obtained in the first thread as shown in Figure 11. The source of the indication was not identified since this was beyond the scope of the project. A comparison with Figure 2 shows that the signal amplitude from this indication is slightly smaller than the ECP signal from a 0.039 in. L. x 0.010 in. D. artificial flaw. No other flaw indications were obtained from this spindle.

Specimen No. 5

ECP data from specimen No. 5 are shown in Figures 15 through 18. Very small indications, slightly above background signal level, were obtained near the end of the spindle in threads 13 and 14. The angular location of these indications correspond with the location of the "0" stamped on the end of the spindle. The source of these indications was not determined.

Specimen No. 6

The ECP signals from specimen No. 6 are shown in Figures 19 through 22. No distinct flaw indications are evident in these data. The slightly higher background level in thread No. 13 was apparently caused by mechanical noise due to the probe holder extending beyond the end of the part.

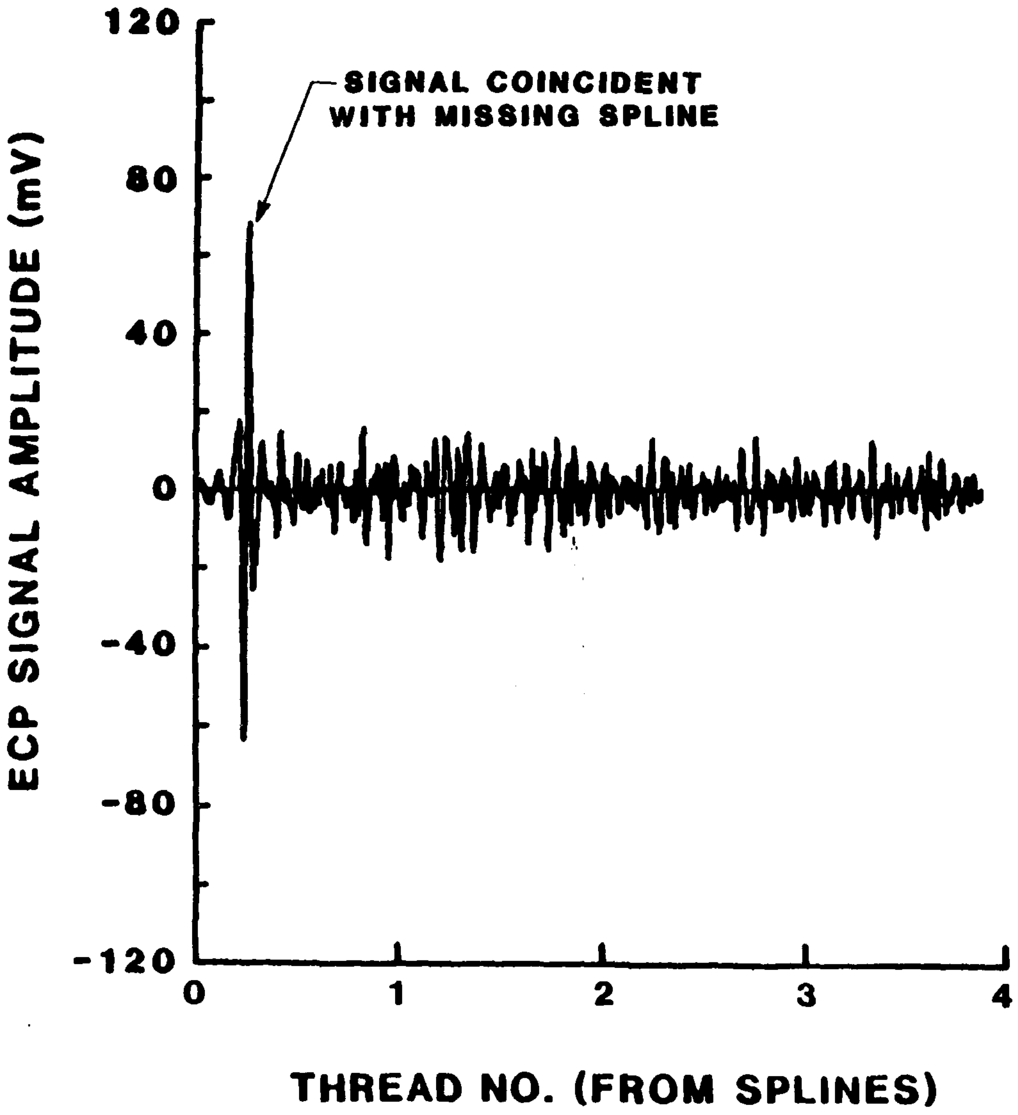

FIGURE 7. ECP SIGNALS FROM SPECIMEN NO. 3, THREADS 0-4

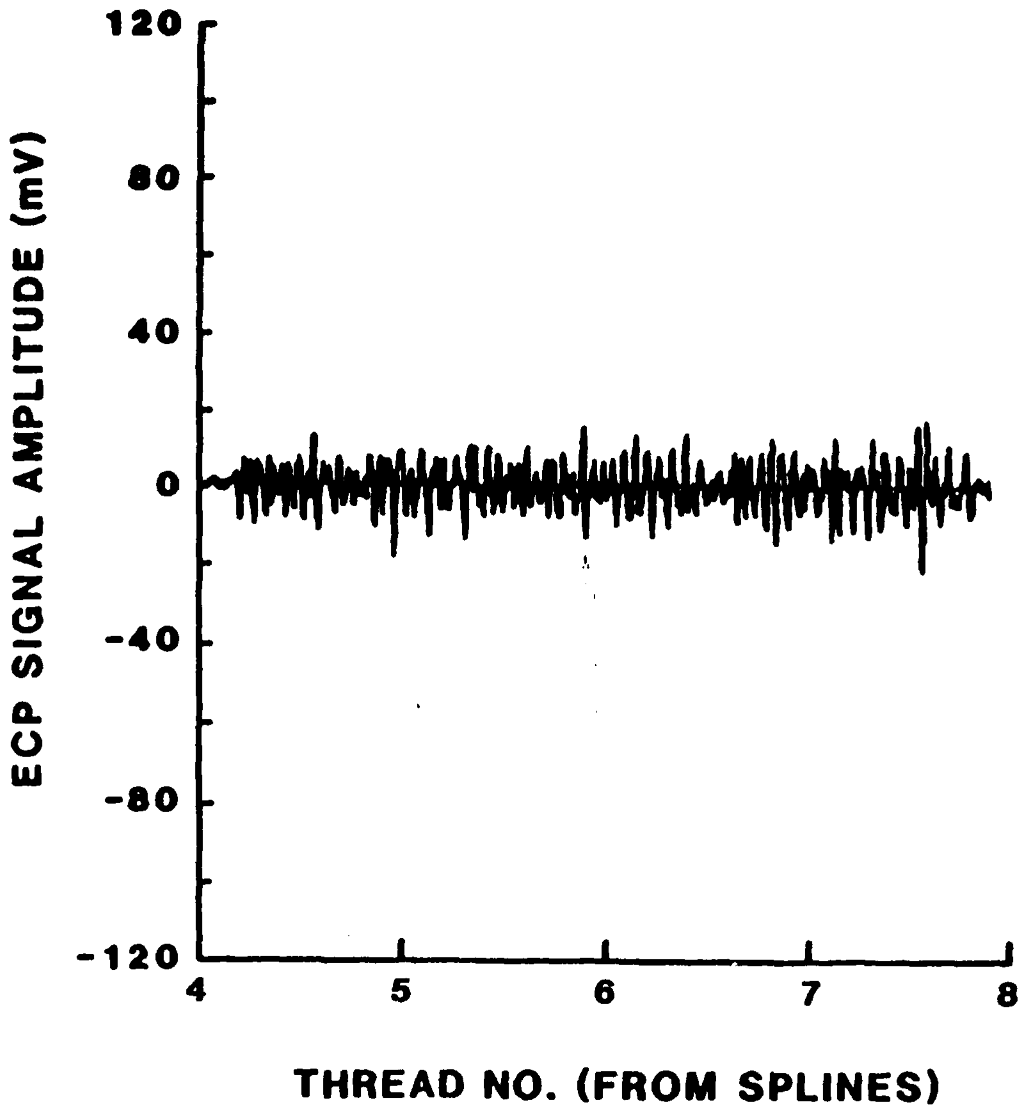

FIGURE 8. ECP SIGNALS FROM SPECIMEN NO. 3, THREADS 4-8

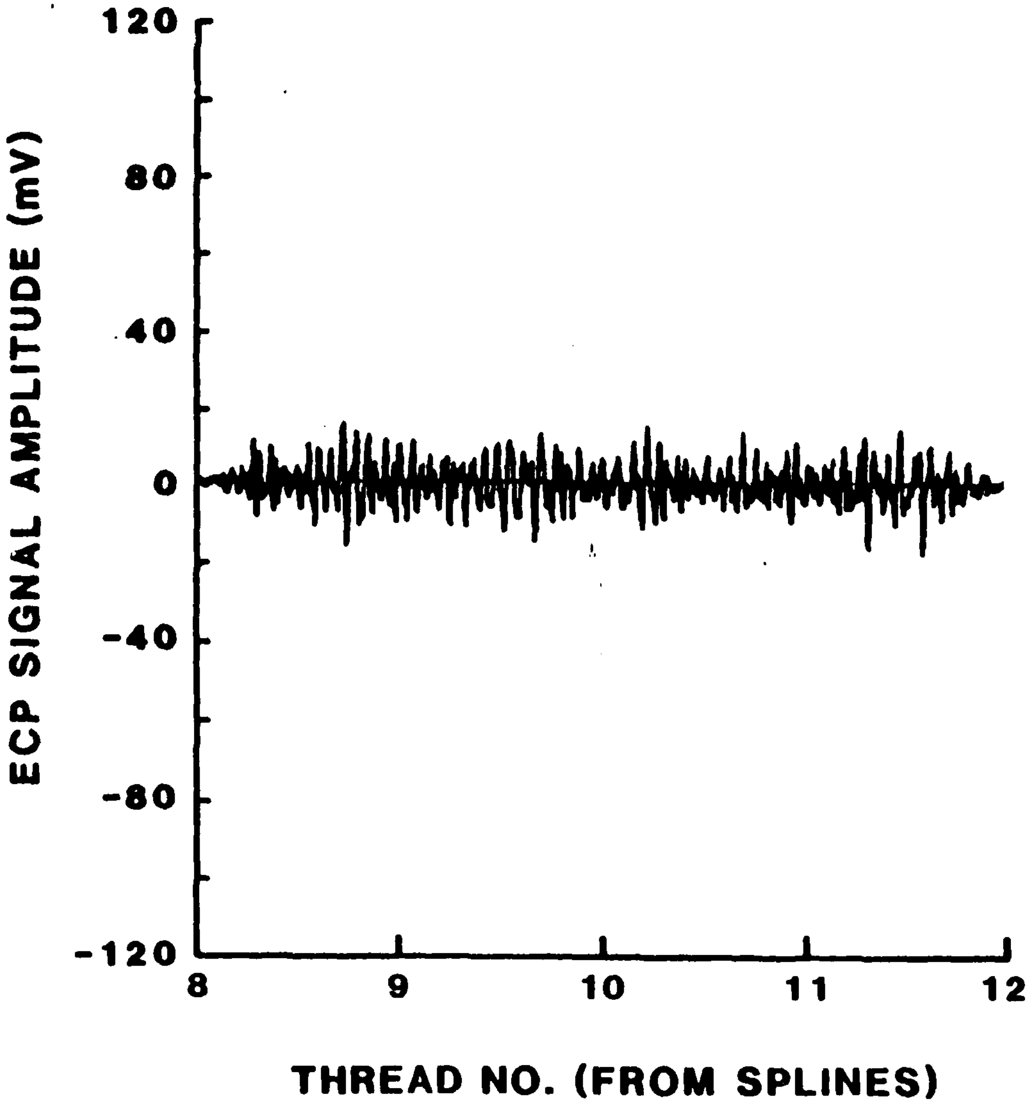

FIGURE 9. ECP SIGNALS FROM SPECIMEN NO. 3, THREADS 8-12

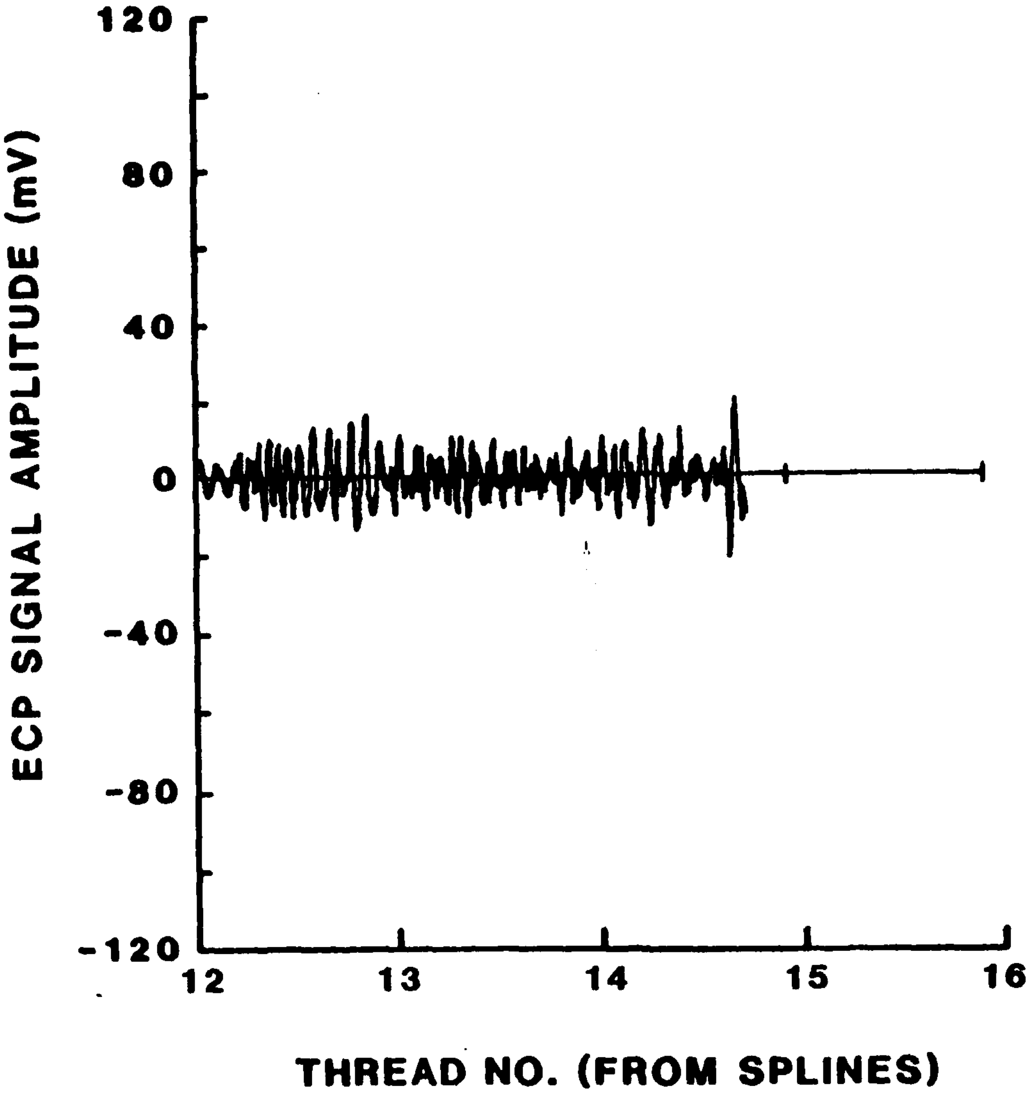

FIGURE 10. ECP SIGNALS FROM SPECIMEN NO. 3, THREADS 12-16

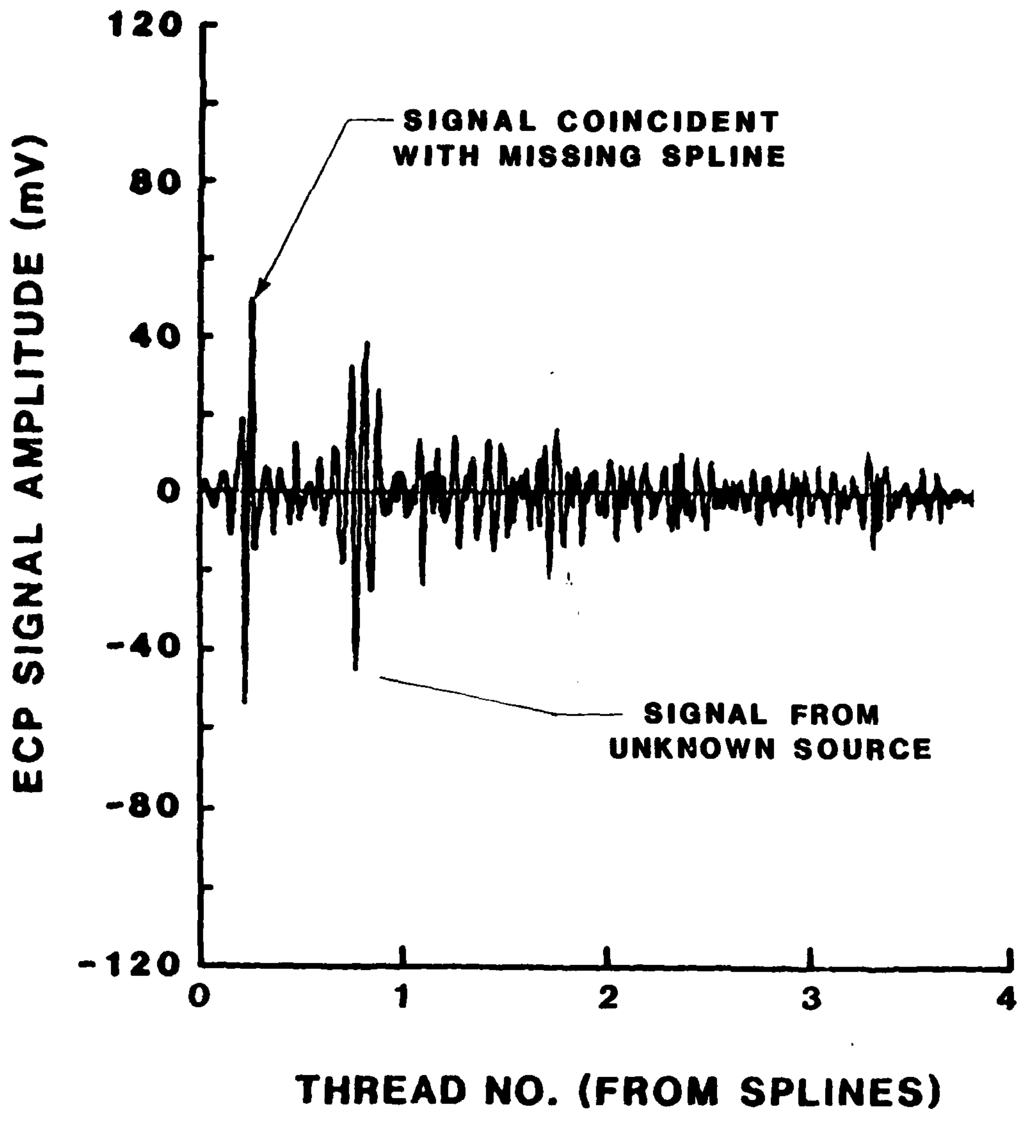

FIGURE 11. ECP SIGNALS FROM SPECIMEN NO. 4, THREADS 0-4

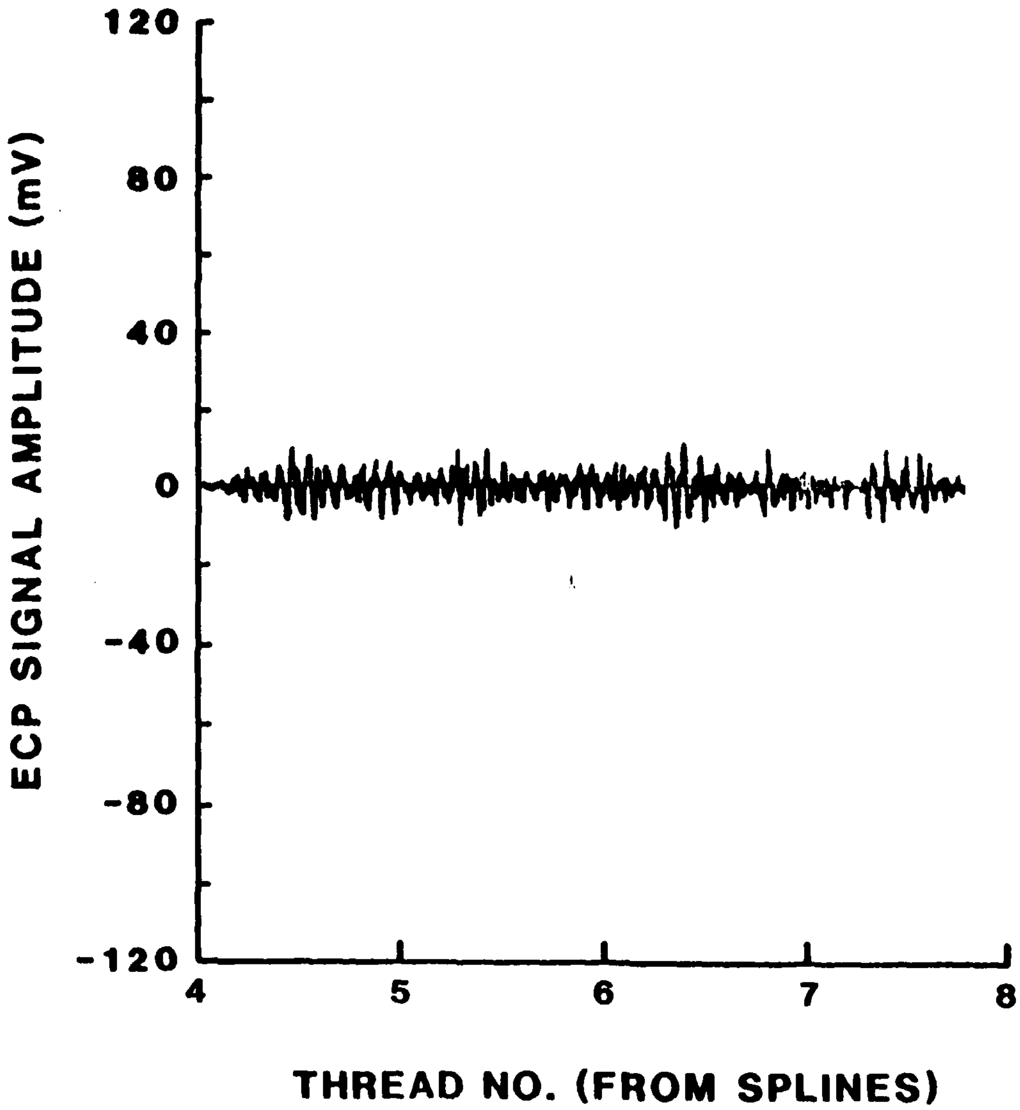

FIGURE 12. ECP SIGNALS FROM SPECIMEN NO. 4, THREADS 4-8

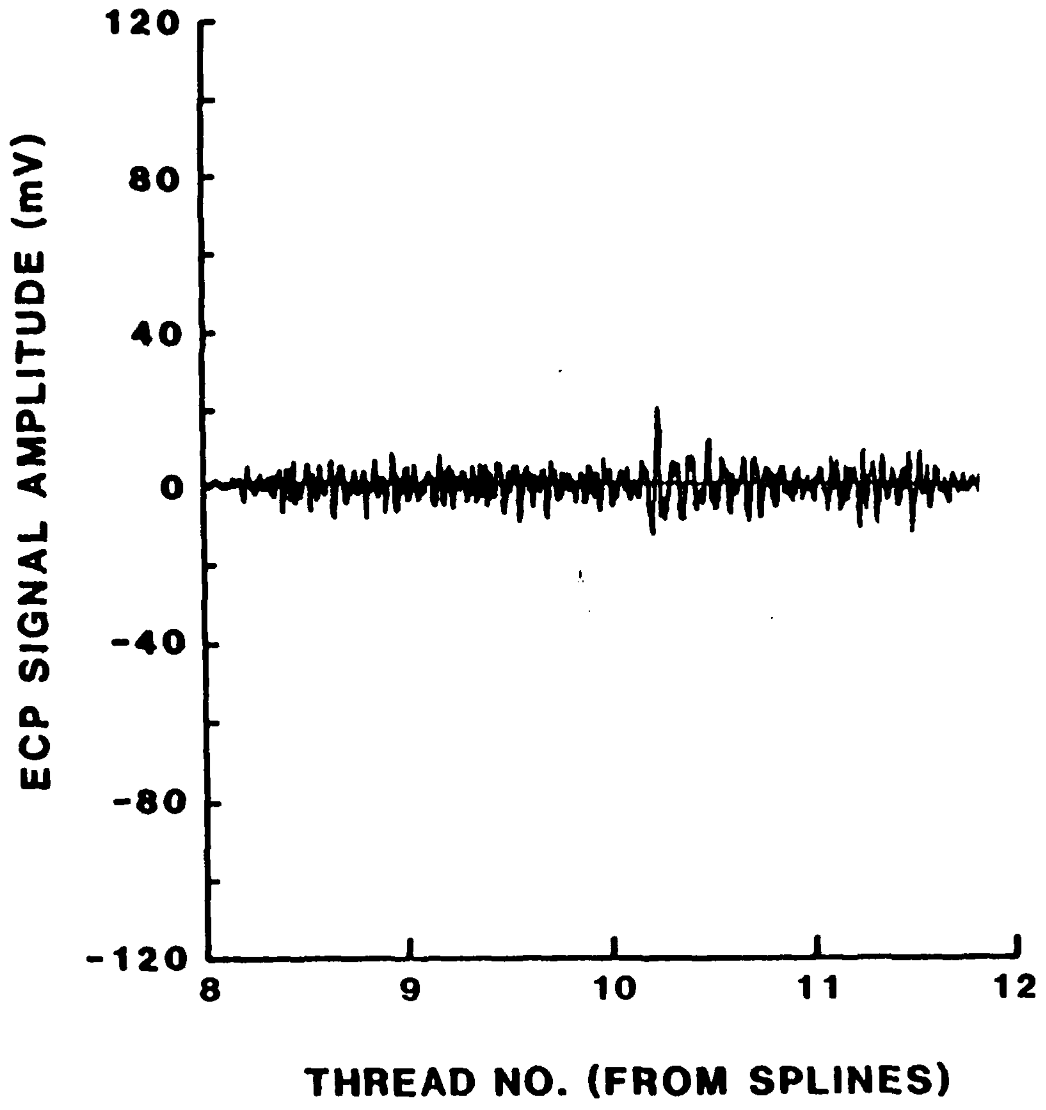

FIGURE 13. ECP SIGNALS FROM SPECIMEN NO. 4, THREADS 8-12

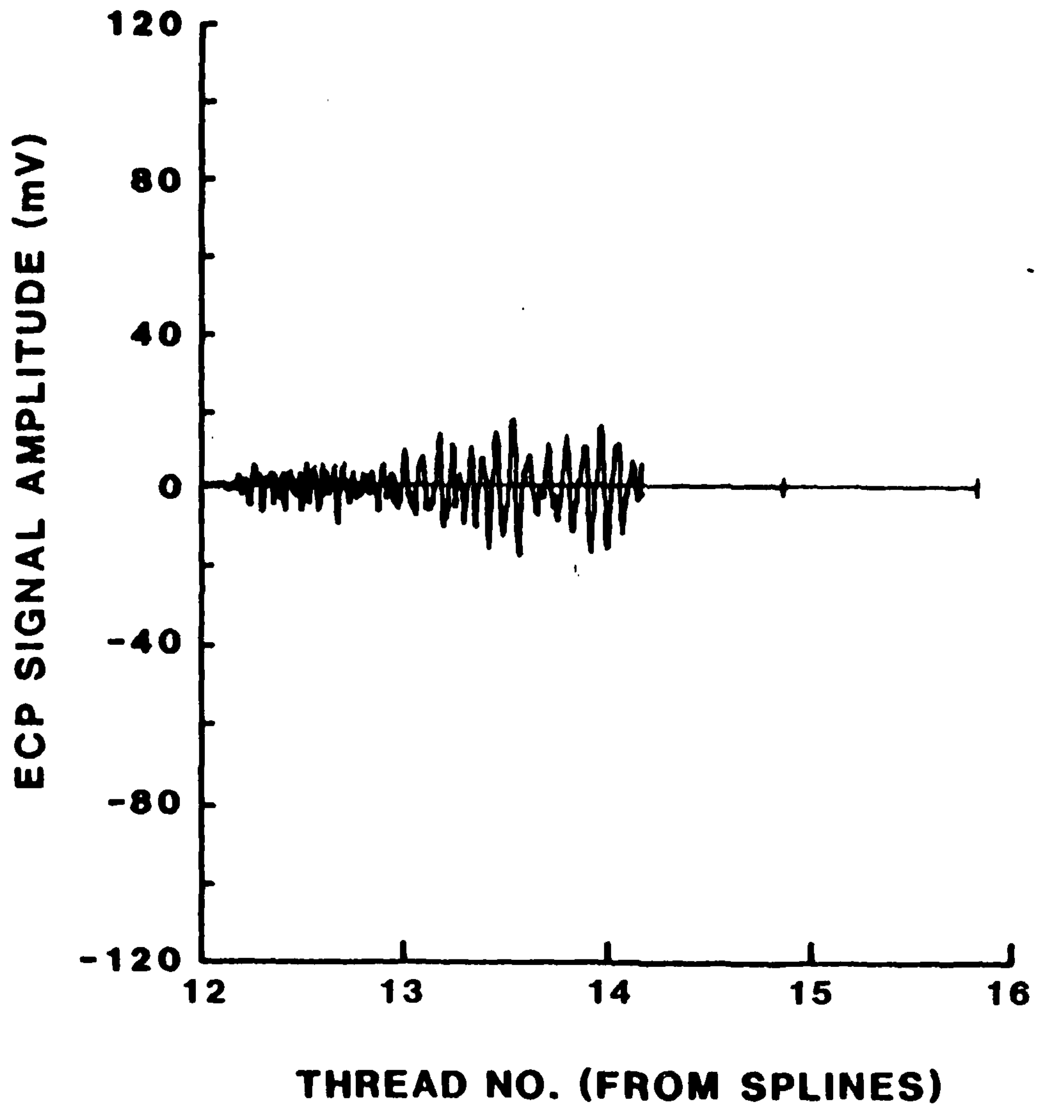

FIGURE 14. ECP SIGNALS FROM SPECIMEN NO. 4, THREADS 12-16

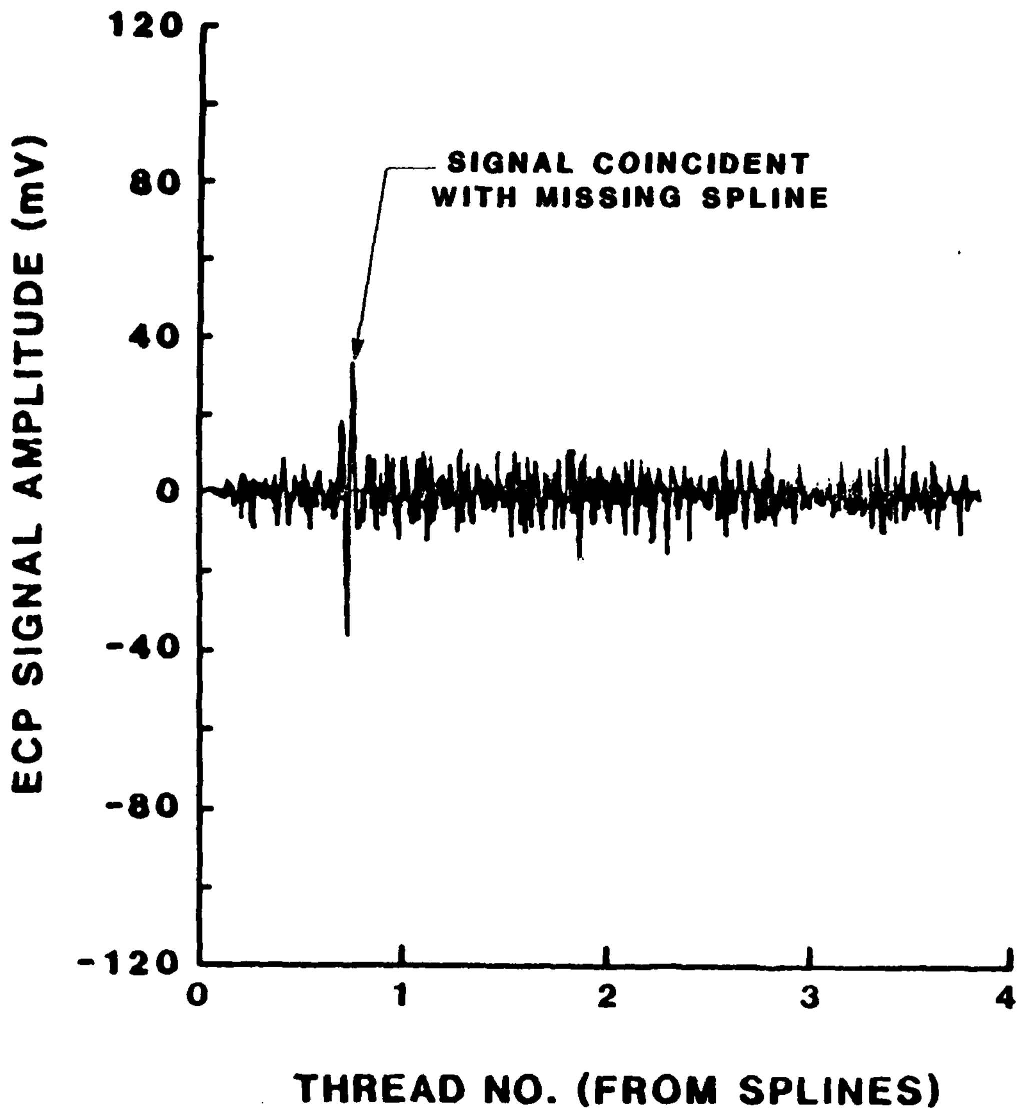

FIGURE 15. ECP SIGNALS FROM SPECIMEN NO. 5, THREADS 0-4

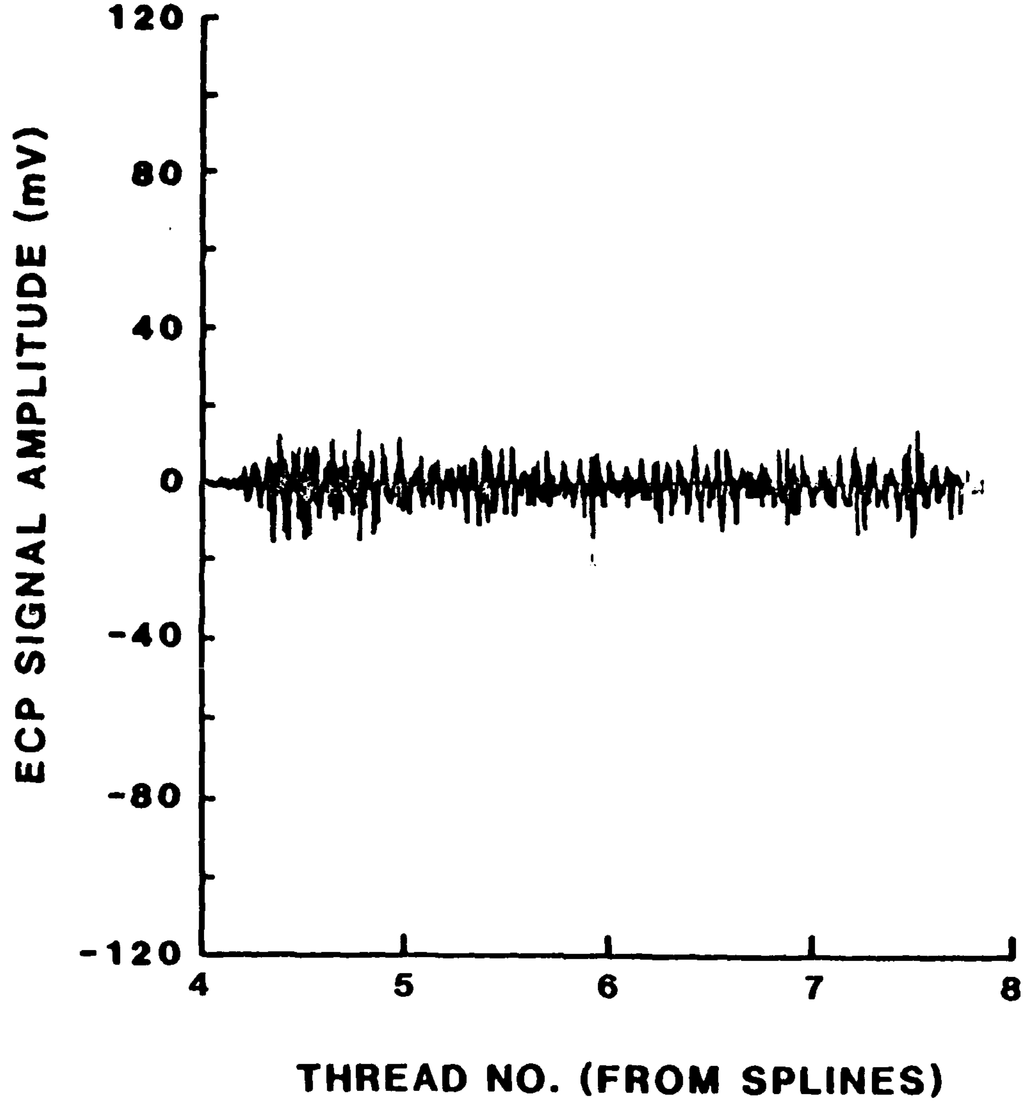

FIGURE 16. ECP SIGNALS FROM SPECIMEN NO. 5, THREADS 4-8

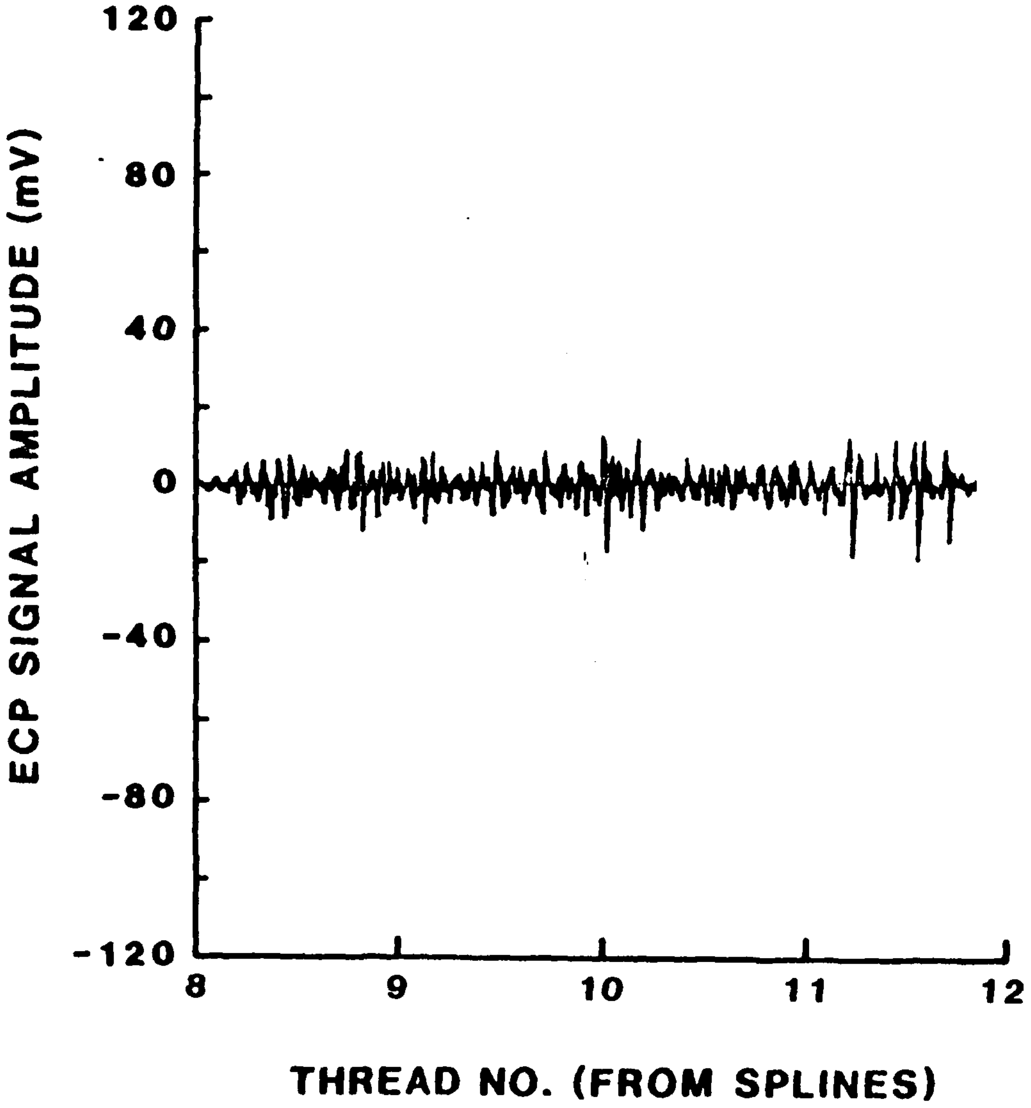

FIGURE 17. ECP SIGNALS FROM SPECIMEN NO. 5, THREADS 8-12

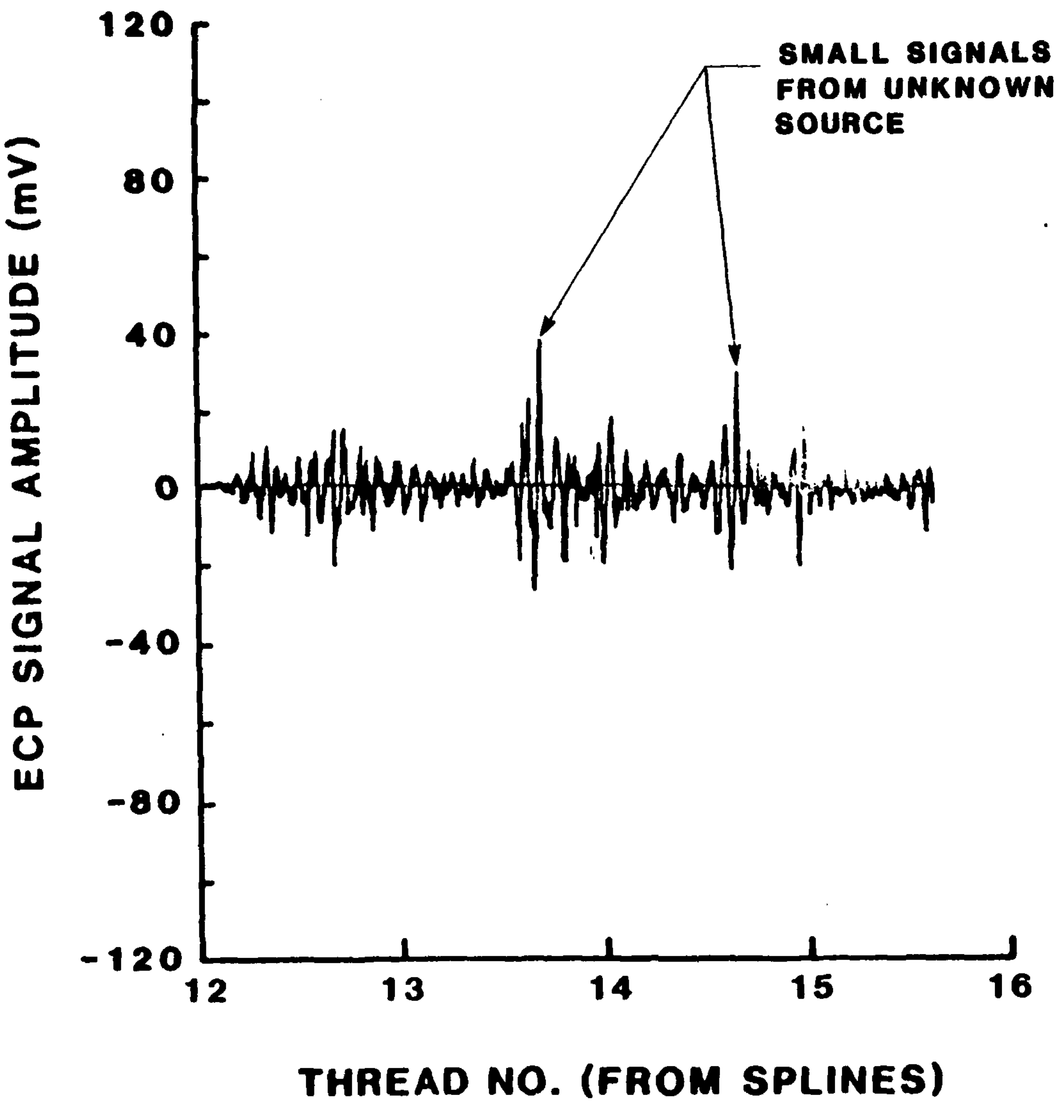

FIGURE 18. ECP SIGNALS FROM SPECIMEN NO. 5, THREADS 12-16

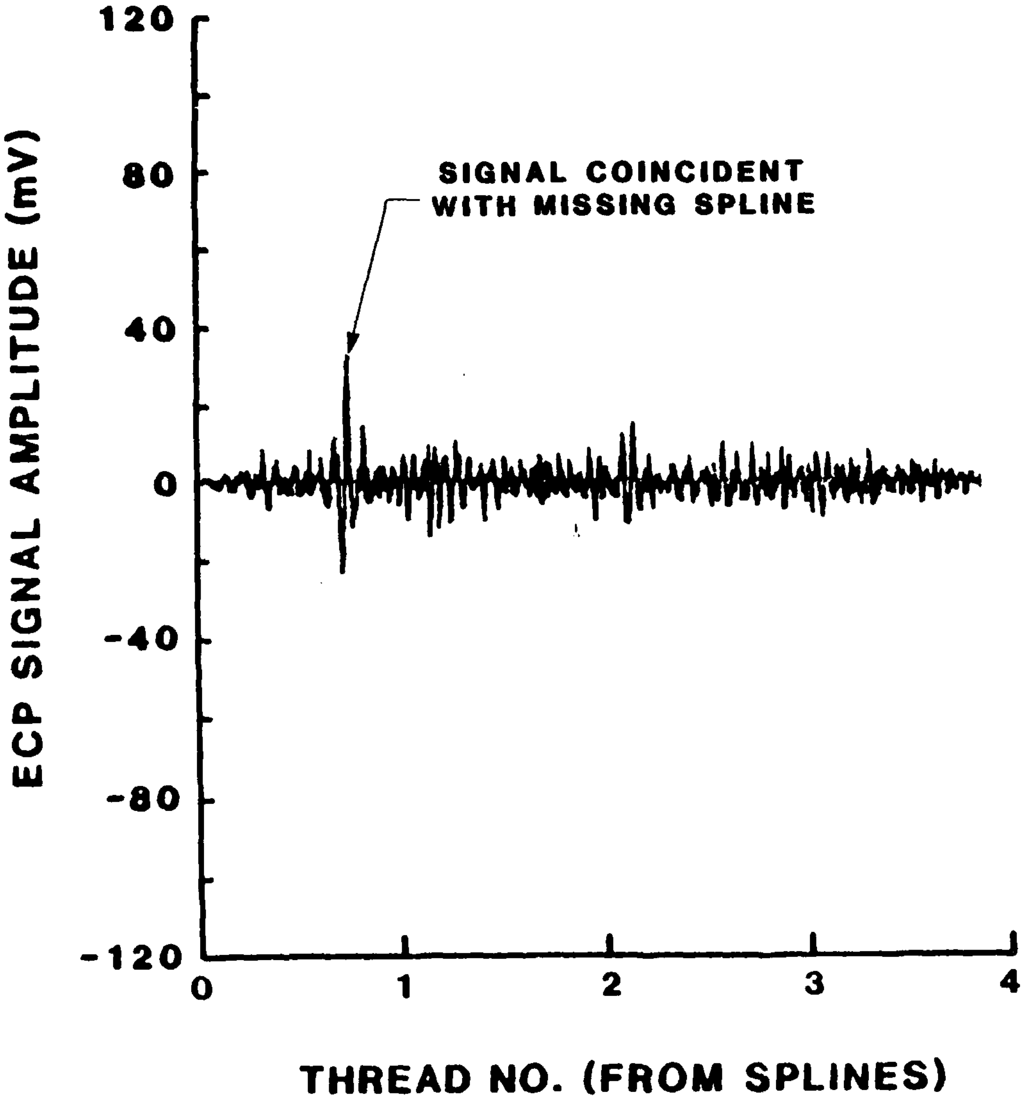

FIGURE 19. ECP SIGNALS FROM SPECIMEN NO. 6, THREADS 0-4

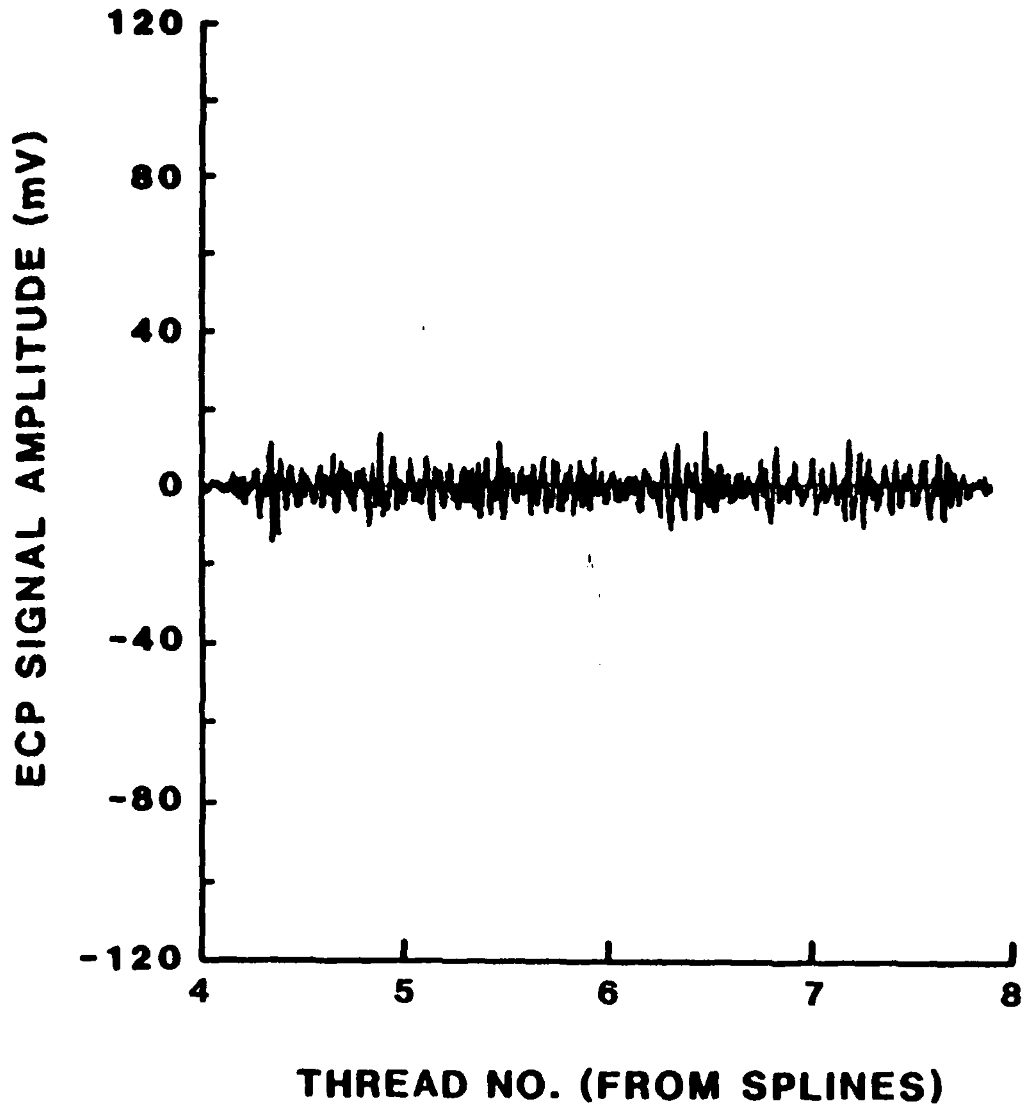

FIGURE 20. ECP SIGNALS FROM SPECIMEN NO. 6, THREADS 4-8

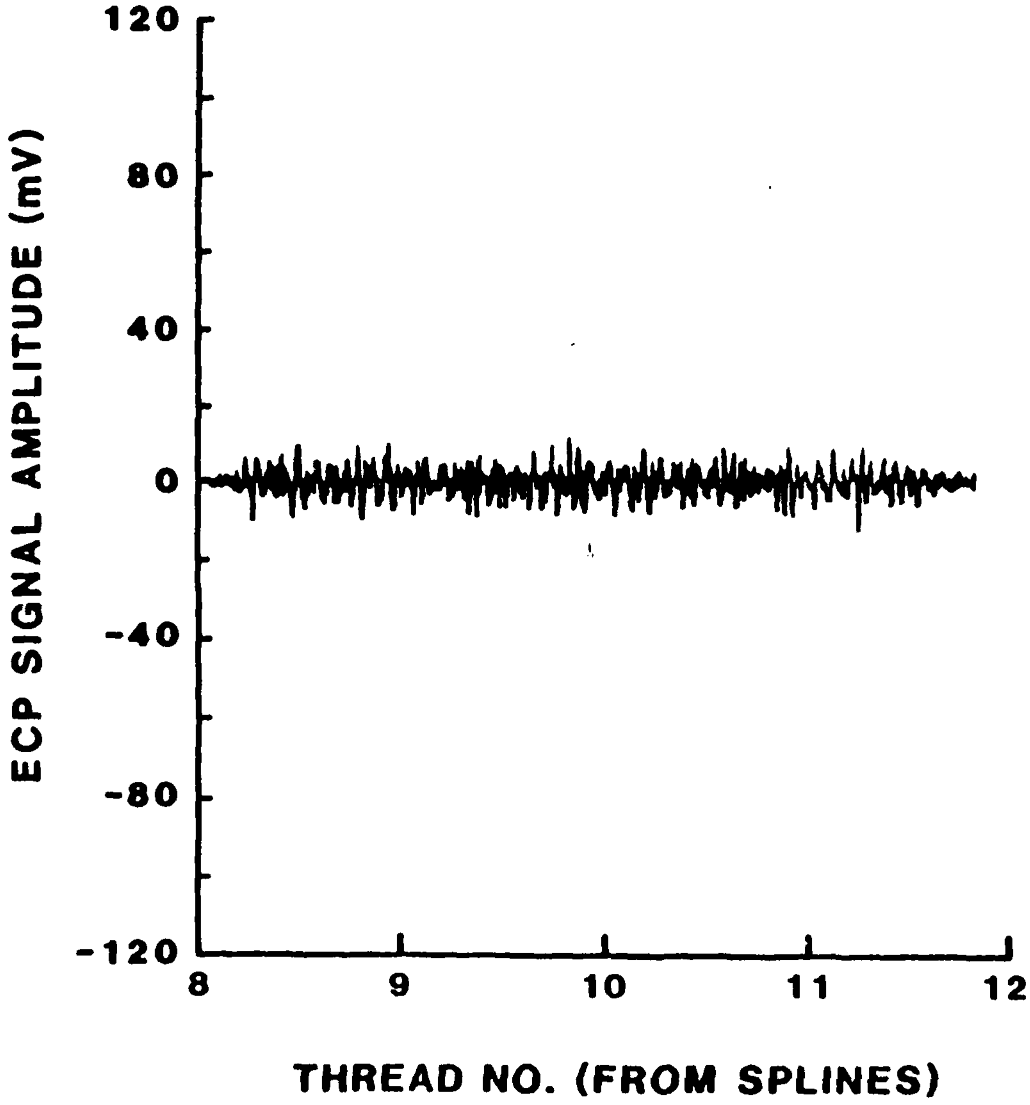

FIGURE 21. ECP SIGNALS FROM SPECIMEN NO. 6, THREADS 8-12

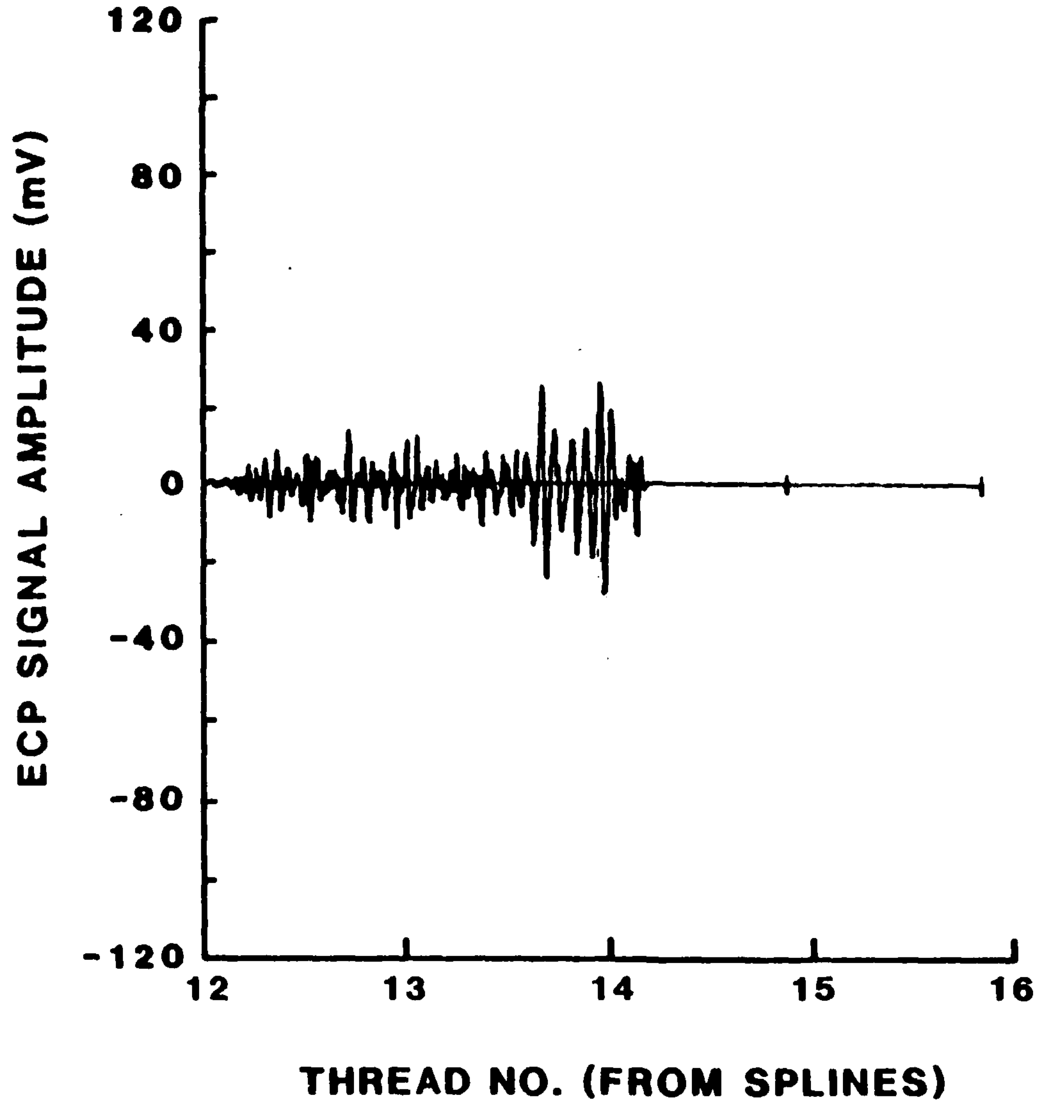

FIGURE 22. ECP SIGNALS FROM SPECIMEN NO. 6, THREADS 12-16

IV. CONCLUSIONS AND RECOMMENDATIONS

The ECP method is very promising for detection of fatigue cracks in the thread roots of the Black Hawk helicopter rotary wing-head spindle. The ECP method provides much higher sensitivity for detection of surface and slightly subsurface flaws than the present ultrasonic method and is not influenced by the presence of a tie rod in the spindle. Inspection of the threads from six spindles (two containing artificial flaws) showed that flaws as small as 0.021 in. L. x 0.009 in. D. are detectable. However, the flaw size must be increased to approximately 0.039 in. L. x 0.010 in. D. to obtain an overall signal-to-background ratio of greater than 2:1. Small indications slightly above background signal level were obtained from two spindles. The sources of these indications were not determined as this was beyond the scope of the project. Although a previous inspection of one spindle gave an ultrasonic indication, ECP indication was not obtained. The ultrasonic indication was from well below the surface and the present ECP probe is designed for detection of surface and slightly subsurface flaw. The ultrasonic indication is most likely not caused by a fatigue cracks since it is expected that a crack would originate on the thread root surface and not well below the surface.

It is recommended that an ECP inspection system be developed for the Black Hawk spindle threads and that ECP data be obtained from a relatively large number of spindles which have been removed from service. The data base obtained from unflawed spindles would allow the background ECP signal level to be determined for a statistically significant number of specimens. Using ECP signal data from artificial flaws, the minimum size flaw that can be reliably detected would be determined. If cracks are detected in these spindles, then ECP data could be correlated with actual crack sizes as determined by metallurgical sectioning*. Upon completion of this evaluation, the ECP method would be used for routine spindle inspections.

*It should be noted that previous laboratory data has shown equivalence of ECP responses from artificial flaws and fatigue cracks.

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1. Burkhardt, G.L. and Teller, C.M., "Demonstration and Analysis of an Improved Nondestructive Evaluation (NDE) Method for Rotary Wing-Head Spindle Threads," Final Report, Contract No. DLA-900-79-C-1266-001AH, June, 1982.